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Strain Analysis of the Equine Metacarpal Bone Diaphysis

[1]Gulsum Ozyigit, [1]Bahri Yildiz and [2]Resat Ozcan
[1]Department of Anatomy, Faculty of Veterinary Medicine,
[2]Department of Mechanical Engineering, Faculty of Engineering and Architecture,
Uludag University, 16059 Gorukle, Bursa, Turkey

Abstract: Diaphyseal third metacarpal fractures are common injuries in horse. The purpose of this study was to determine the strain values from proximal to distal on the medial and lateral regions of Mc_3 diaphysis. Left Mc_3 256 mm length was used. Strain gages were located on the lateral and medial regions of the bone diaphysis. Diaphyseal length was 204 mm and strain gauges were spaced at 4 cm intervals. Strain gauges were numbered from proximal to distal. The 500-1000-1200-1600 ve 1800 N forces were applied on the bone with using computer aided Instron 4301 instrument with 5 kN capacity. Strains on the lateral side were observed to be compressive and on the medial side they were tensile. Compressive strains on lateral regions were significantly higher than tensile strains on medial regions. Maximum strain values were found on the distal ends in both sides of the diaphysis and distal lateral end of the bone has maximum strain.

Key words: Equine, metacarpal bone, diaphysis, strain, horse, distal, lateral end

INTRODUCTION

Third Metacarpal (Mc_3) bone fractures in horses is one of the most common stress fractures (Mckee, 1995; Gibson *et al*., 2006). Diaphyseal fractures of the Mc_3 bone compose 22% of all horse limb fractures. Because of the limited soft tissue envelope in this area, open fractures are common, frequently the result of the sharp fracture fragments penetrating the skin (Mckee, 1995; Watkins, 2006). The 12% of those racehorses develop stress fractures at the dorsal or dorsolateral aspect of Mc_3 during the racing (Nunamaker, 1996). Pain and inflammation on the dorsal surface of the Mc_3 referred to as shin soreness is most common in racehorses. Shin soreness develops as a result of increased strain on the Mc_3 from training in high speed of young horses, concussions and contusions (Nunamaker, 2000). Fractures of the condyles are the most common long bone fractures of the Mc_3 and Mt_3 in horses in training (Ferraro, 1990; Ellis, 1994). For these reasons Mc_3 and Mt_3 bones of the horse is the most studied bone for its structural characteristics (Nunamaker *et al*., 1989; Stover *et al*., 1992), mechanical features (Turner *et al*., 1975; Biewener *et al*., 1983; Nunamaker *et al*., 1990; Les *et al*., 1997) and stiffness (Nunamaker *et al*., 1991; Gibson *et al*., 1995).

The goal of the present study were to determine the resistance from proximal to distal on the medial and lateral regions of Mc_3 diaphysis.

MATERIALS AND METHODS

In the study, left Mc_3 was obtained from a native horse of with the weight 350 kg that was brought to the Department of Anatomy as a course cadaver and having no problem related to locomotor system was used. The bone was removed from the body and stored in 0.9% saline solution at -20°C until required (Les *et al*., 2002).

This was fallowed by the attachment of strain gauges onto medial and lateral sides of bones. Five strain gauges were used for each sides of bone (Micro-Measurements EA-06-062AK-120 ohm resistance, gage factor of 2.035). The length of the bone was 256 mm and diaphyseal length was 204 mm and strain gauges were spaced at 4 cm intervals. Strain gauges were numbered from proximal to distal.

Placement sites were gently curreted before the strain gauges were attached. The surface of the bones were cleaned and degreased with ether. Gauges were glued to the bone with epoxy resin (M-Bond Adhesive Resin, Micro-Measurement) and kept in position by manual pressure for 1 min. Thereafter, the cables to be used for connecting the strain gauges and terminals with the measurement set were soldered to strain gauges and terminals. With this purpose, three cables with 1 m length were used for each strain gage-terminal pair. Strain gauges and terminals were covered with silicone for protection from external effects because of the sensitivity

Corresponding Author: Gulsum Ozyigit, Department of Anatomy, Faculty of Veterinary Medicine, Uludag University, 16059 Gorukle, Bursa, Turkey

of all systems. After that the bone were fixed at their distal parts by polyester molding in order to provide the limit conditions (Fig. 1).

After this last stage, compression experiments were started on the bones. The 500-1000-1200-1600 ve 1800 N forces were applied on the bones. The trials were carried out using computer-aided Instron 4301 instrument with 5 kN capacity. Changes in the zone in which strain gage was attached as a result of the force applied were determined numerically using strain gage measurement set.

Statistical analysis: The statistical procedures were done by using the Least Square Means (LSM-PROG GLM) of the statistical analysis software program SAS. The p-values of 0.05 or less were considered significant.

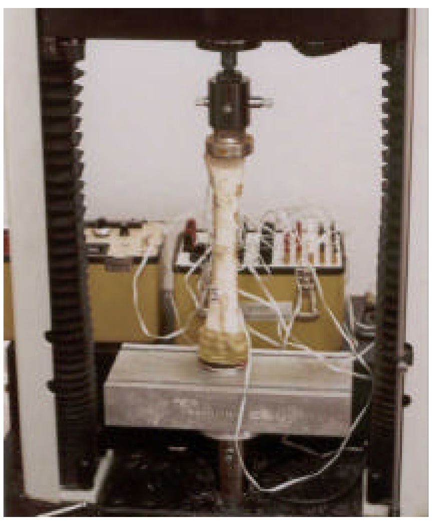

Fig. 1: Applied pressures to sample. Computer-aided Instron 4301 instrument and strain gage measurement set were used

RESULTS AND DISCUSSION

In this study left Mc_3 bone from one native horse were used. Exercise histories were not available. Strains recorded from the strain gauges placed to the diaphysis of the bone. Table 1 and 2 show strain results for the axial compression tests and strain changes are shown in Fig. 2 and 3.

The values of strain obtained from tests were negative and positive in lateral and medial sides, respectively suggesting that strains on the lateral side were observed to be compressive and on the medial side they were tensile.

It was also observed that under all loading conditions strain values on lateral side were higher than strain values on medial side for all strain gages. Maximum strain values were found on the distal ends in both sides of the diaphysis (p = 0.0001) and distal lateral end of the bone has maximum strain.

Strain values were increasing from proximal to distal. Surface bone strains increased with the increasing load and strain values on the distal area were found significantly (p<0.001) higher than on the proximal area. There were no statistically differences between strain values from SG #1 and SG #3 for 500, 1000, 1400, 1600 and 1800 and from SG #3 and SG #4 for 1200 N on lateral side. There were significant differences between other strain gages in all lateral side (p = 0.0001) (Table 3). There were no statistically differences between strain values from SG#2 and SG#3 for 500 N on medial side. There were significant differences between other strain gages in all medial side (p = 0.0001) (Table 4).

There were no meaningful changes between strain values obtained from strain gages from proximal to distal on the medial side.

Table 1: Strain values on medial side of the diaphysis of Mc_3 bone

	Strain values on medial side							
	Strain gauge # 1				Strain gauge # 2			
Load (N)	Exp. 1	Exp. 2	Exp. 3	Mean	Exp. 1	Exp. 2	Exp. 3	Mean
500	17.43	14.32	16.11	15.95	35.98	38.54	36.67	37.06
1000	31.75	35.52	33.73	33.67	56.87	51.43	57.12	55.14
1200	49.87	43.72	47.53	47.04	83.44	87.77	80.56	83.92
1400	61.57	58.12	64.75	61.48	74.89	73.24	74.31	74.15
1600	76.42	70.92	75.35	74.23	68.23	69.56	65.43	67.74
1800	90.45	81.62	86.76	86.28	88.40	89.56	83.10	87.02

	Strain gauge # 3				Strain gauge #4				Strain gauge # 5			
Load (N)	Exp. 1	Exp. 2	Exp. 3	Mean	Exp. 1	Exp. 2	Exp. 3	Mean	Exp. 1	Exp. 2	Exp. 3	Mean
500	39.09	35.78	36.89	37.25	58.32	62.01	60.17	60.17	77.90	79.43	77.98	78.44
1000	62.21	77.54	75.54	71.76	127.23	129.08	126.81	127.71	190.85	191.12	193.56	191.84
1200	84.33	81.22	87.66	84.40	163.35	165.45	163.78	164.19	225.65	224.99	225.46	225.37
1400	105.45	101.47	110.13	105.68	176.99	173.58	175.99	175.52	267.86	265.69	268.23	267.26
1600	125.57	121.24	127.25	124.69	194.64	195.31	193.98	194.64	311.45	314.56	312.34	312.78
1800	144.69	146.45	147.91	146.35	223.21	221.11	223.18	222.50	498.37	501.76	497.86	499.33

*Exp: Experiment, N: Newton. The negative sign (-) signifies compressive loads

Table 2: Strain values on lateral side of the diaphysis of Mc_3 bone

	Strain values on lateral side							
	Strain gauge # 1				Strain gauge # 2			
Load (N)	Exp. 1	Exp. 2	Exp. 3	Mean	Exp. 1	Exp. 2	Exp. 3	Mean
500	-186.34	-182.81	-179.58	-182.91	-148.11	-145.69	-141.20	-145.00
1000	-337.28	-333.67	-369.10	-346.68	-293.13	-288.34	-295.17	-292.21
1200	-425.08	-418.70	-412.13	-418.64	-368.83	-331.68	-350.49	-350.33
1400	-464.34	-436.24	-442.20	-447.59	-395.40	-380.34	-386.01	-387.25
1600	-528.78	-517.29	-519.86	-521.98	-467.89	-451.78	-434.22	-451.30
1800	-611.67	-630.27	-614.04	-618.66	-487.45	-485.76	-490.13	-487.78

	Strain gauge # 3				Strain gauge #4				Strain gauge # 5			
Load (N)	Exp. 1	Exp. 2	Exp. 3	Mean	Exp. 1	Exp. 2	Exp. 3	Mean	Exp. 1	Exp. 2	Exp. 3	Mean
500	-191.79	-185.56	-176.33	-184.56	-223.10	-206.71	-201.92	-210.58	-251.42	-243.23	-259.58	-251.41
1000	369.10	-359.89	-338.21	-355.73	-381.88	-387.56	-394.55	-388.00	-422.37	-439.45	-452.25	-438.02
1200	-465.17	-463.78	-457.32	-462.09	-492.19	-487.38	-472.43	-484.00	-531.47	-555.12	-567.68	-551.42
1400	-488.32	-483.34	-476.63	-482.76	-525.63	-519.77	-503.26	-516.22	-601.23	-587.34	-621.12	-603.23
1600	-544.08	-519.56	-557.71	-540.45	-610.13	-590.12	-613.43	-604.56	-682.99	-675.92	-691.47	-683.46
1800	-614.04	-623.82	-603.11	-613.66	-681.20	-672.23	-687.57	-680.33	-773.03	-766.10	-785.76	-774.96

*Exp: Experiment, N: Newton

Table 3: Mean strain values and standard deviations (mean±SD) for medial diphyseal region of Mc_3

	Strain values on medial side					
Load	500 N	1000 N	1200 N	1400 N	1600 N	1800 N
Strain gauge # 1	15.96 ± 1.56^{d}	33.66 ± 1.88^{e}	47.04 ± 3.10^{d}	61.48 ± 3.31^{e}	74.23 ± 2.91^{e}	86.27 ± 4.43^{e}
Strain gauge # 2	37.06 ± 1.32^{c}	55.14 ± 3.21^{d}	43.92 ± 3.62^{c}	74.14 ± 0.83^{d}	67.74 ± 2.10^{d}	87.02 ± 3.44^{d}
Strain gauge # 3	37.25 ± 1.68^{c}	71.76 ± 8.33^{c}	84.40 ± 3.22^{c}	105.68 ± 4.33^{c}	174.68 ± 3.00^{c}	146.35 ± 1.61^{c}
Strain gauge # 4	60.16 ± 1.84^{b}	127.70 ± 1.20^{b}	164.19 ± 1.10^{b}	175.52 ± 1.75^{b}	194.64 ± 0.66^{b}	222.50 ± 1.20^{b}
Strain gauge # 5	78.43 ± 0.86^{a}	192.20 ± 1.91^{a}	225.36 ± 0.33^{a}	267.26 ± 1.37^{a}	312.78 ± 1.60^{a}	499.33 ± 2.10^{a}
p-value	****	****	****	****	****	****

*a-d: Different letters within the same column indicate significant differences among the groups (p = 0.0001) **** p = 0.0001

Table 4: Mean strain values and standard deviations (mean±SD) for lateral diphyseal region of Mc_3

	Strain values on lateral side					
Load	500 N	1000 N	1200 N	1400 N	1600 N	1800 N
Strain gauge # 1	182.91 ± 3.380^{c}	346.68 ± 19.49^{c}	418.63 ± 6.470^{c}	447.59 ± 14.80^{c}	521.97 ± 6.030^{c}	618.66 ± 10.12^{c}
Strain gauge # 2	145.00 ± 3.500^{d}	292.21 ± 3.500^{d}	350.33 ± 13.57^{d}	387.25 ± 7.600^{d}	451.29 ± 16.84^{d}	487.78 ± 2.200^{d}
Train gauge # 3	184.56 ± 7.770^{c}	355.73 ± 15.85^{c}	462.09 ± 4.180^{b}	482.76 ± 5.860^{c}	540.45 ± 19.33^{c}	613.65 ± 10.36^{c}
Strain gauge # 4	210.57 ± 11.10^{b}	387.99 ± 6.340^{b}	484.00 ± 10.30^{b}	516.22 ± 11.59^{b}	604.56 ± 12.61^{b}	680.33 ± 7.700^{b}
Strain gauge # 5	251.41 ± 8.170^{a}	438.02 ± 14.99^{a}	551.42 ± 18.38^{a}	603.23 ± 16.97^{a}	683.46 ± 7.780^{a}	774.96 ± 9.970^{a}
p-value	****	****	****	****	****	****

*a-d: Different letters within the same column indicate significant differences among the groups (p = 0.0001); ****p = 0.0001

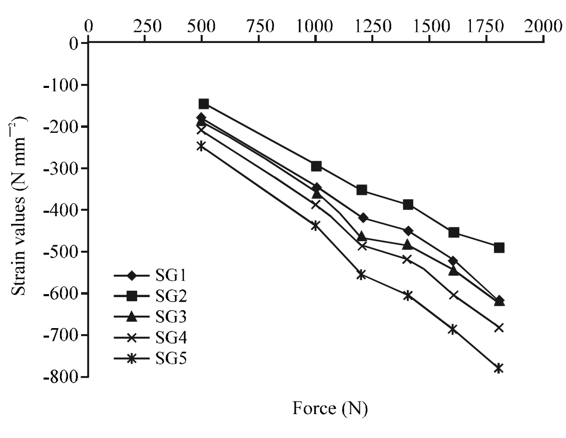

Fig. 2: Changing strain values on lateral side of the diaphysis of Mc_3 bone. *SG1-2-3-4-5: Strain gage 1-2-3-4 and 5

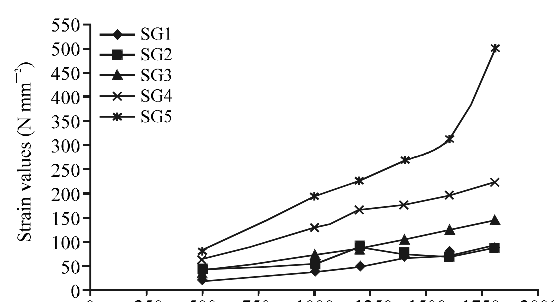

Fig. 3: Changing strain values on medial side of the diaphysis of Mc_3 bone. *SG1-2-3-4-5: Strain gage 1-2-3-4 and 5

Compressive strains on lateral regions were significantly ($p<0.001$) higher than tensile strains on medial regions. Diaphyseal Mc_3 bone fractures are common injuries in horse. Epidemiological studies have shown that about 70% of young Thoroughbreds in race training bucked their shins and that about 12% of those racehorses develop stress fractures at the dorsal or dorsolateral aspect of Mc_3 during the following racing season (Norwood, 1978; Nunamaker, 1996; Carstanjen *et al*., 2003).

Strains on the lateral side were observed to be compressive and on the medial side they were tensile. Mc_3 bone is loaded axially (Watkins, 2006; Merritt *et al*., 2010). The medial and dorsal regions have less tensile strain resistance than the other regions in Mc_3 (Turner *et al*., 1975; Ozyigit and Ozcan, 2010). Lateral region has the greatest elastic modulus and static strength than medial region (Gibson *et al*., 1995, 2006). The lateral cortex was strongest and stiffest (Martin *et al*., 1997). Lateral region also has the highest longitudinal fiber values than medial region (Martin *et al*., 1996). The dorsomedial aspect is also the most common site for stress fractures in Thoroughbred racehorses (Nunamaker *et al*., 1991). Differences in crack growth initiation toughness demonstrate that the lateral bone tissue is more resistant to crack growth initiation than is tissue in the dorsal region (Malik *et al*., 2003). Strains on the medial side were observed to be tensile. This region is the critacal region for fractures due to the bones had low resistance to tensile strain. Bone is strongest in compression and weakest in tension (Martin *et al*., 1996; Nunamaker, 2002).

Third metacarpal compact bone shows variation in thickness from proximal to distal. Compact region of Mc_3 is observed to be thicker in the middle of the body but thinner in the terminals (Carter and Hayes, 1976). Local variation in equine metacarpal cortical material has also been demonstrated, both along the proximodistal axis and regionally within a proximodistal level. Areas of higher bone mineral densities and lower fracture toughness have been found in the proximal diaphysis The bone stiffness increases with the load rate (Hanson *et al*., 1995; Les *et al*., 2002). The researchers observed that surface bone strains increased with the increasing load and strain values on the distal area were found significantly higher than on the proximal area.

In this study maximum strain values were found on the distal ends in both sides of the diaphysis and distal lateral end of the bone has maximum strain. This strain may extend distally into the lateral condyle. Fractures of the lateral condyle are most common than fractures of the medial condyle of Mc_3 bone in horses (Mckee, 1995; Parkin *et al*., 2004, 2006).

CONCLUSION

In the study, tensile strains on medial regions were significantly higher than compressive strains on lateral regions and maximum strain values were found on the distal lateral end of the bone. Mc_3 bone is loaded mainly in axial compression and as a results of the present study medial diaphyseal side and lateral distal diaphyseal end of a Mc_3 bone can be critical sides for diaphyseal deformation.

REFERENCES

Biewener, A.A., J. Thomason, A. Goodship and L.E. Lanyon, 1983. Bone stress in the horse forelimb during locomotion at different gaits: A comparison of two experimental methods. J. Biomech., 16: 565-576.

Carstanjen, B., O.M. Lepage, O. Hars, P. Langlois, F. Duboeuf and H. Amory, 2003. Speed of sound measurements of the third metacarpal bone in young exercising thoroughbred racehorses. Bone, 33: 411-418.

Carter, D.R. and W.C. Hayes, 1976. Bone compressive strength: The influence of density and strain rate. Science, 194: 1174-1176.

Ellis, D.R., 1994. Some observations on condylar fractures of the third metacarpus and third metatarsus in young Thoroughbreds. Equine Vet. J., 26: 178-183.

Ferraro, G.L., 1990. Lameness diagnosis and treatment in the *Thoroughbred racehorse*. Vet. Clin. North Am.. Equine Pract., 6: 63-84.

Gibson, V.A., S.M. Stover, J.C. Gibeling, S.J. Hazelwood and R.B. Martin, 2006. Osteonal effects on elastic modulus and fatigue life in equine bone. J. Biomech., 39: 217-225.

Gibson, V.A., S.M. Stover, R.B. Martin, J.C. Gibeling, M.B. Gustafson and L.V. Griffin, 1995. Fatigue behavior of the equine third metacarpus: Mechanical property analysis. J. Orthopaedic Res., 13: 861-868.

Hanson, P.D., M.D. Markel and R. Vanderby, 1995. Diaphyseal structural properties of equine long bones. Am. J. Vet. Res., 56: 233-240.

Les, C.M., S.M. Stover, J.H. Keyak, K.T. Taylor and A.J. Kaneps, 2002. Stiff and strong compressive properties are associated with brittle post-yield behavior in equine compact bone material. J. Orthopaedic Res., 20: 607-614.

Les, C.M., S.M. Stover, J.H. Keyak, K.T. Taylor and N.H. Willits, 1997. The distribution of material properties in the equine metacarpus. J. Biomech., 30: 355-361.

Malik, C.L., S.M. Stover, R.B. Martin and J.C. Gibeling, 2003. Equine cortical bone exhibits rising R-curve fracture mechanics. J. Biomech., 36: 191-198.

Martin, R.B., S.T. Lau, P.V. Mathews, V.A. Gibson and S.M. Stover, 1996. Collagen fiber organization is related to mechanical properties and remodeling in equine bone. A comparsion of two methods. J. Biomech., 29: 1515-1521.

Martin, R.B., V.A. Gibson, S.M. Stover, J.C. Gibeling and L.V. Griffin, 1997. Residual strength of equine bone is not reduced by intense fatigue loading: Implications for stress fracture. J. Biomech., 30: 109-114.

Mckee, S.L., 1995. An update on racing fatalities in the UK. Equine Vet. Educ., 7: 202-204.

Merritt, J.S., M.G. Pandy, N.A.T. Brown, C.R. Burvill, C.E. Kawcak, C.W. McIlwraith and H.M.S. Davies, 2010. Mechanical loading of the distal end of the third metacarpal bone in horses during walking and trotting. Am. J. Vet. Res., 71: 508-514.

Norwood, G.L., 1978. The bucked shin complex in Thoroughbreds. Proc. Ann. Convention Am. Assoc. Equine Practitioners, 24: 319-336.

Nunamaker, D.M., 1996. Metacarpal Stress Fractures. In: Equine Fracture Repair, Nixon, A.J. (Ed.). WB Saunders Co., Philadelphia, pp: 195-199.

Nunamaker, D.M., 2000. Aetiopathogenesis of fatigue fracture in *Thoroughbred racehorses*. Proceedings of the 10th European Society of Veterinary Orthopaedics and Traumatology Congress, (ESVOTC'00), Munich, pp: 108-108.

Nunamaker, D.M., 2002. On bone and fracture treatment in the horse. Proc. Am. Assoc. Equine Practnr., 48: 90-101.

Nunamaker, D.M., D.M. Butterweck and J. Black, 1991. *In vitro* comparison of thoroughbred and standardbred racehorses with regard to local fatigue failure of the third metacarpal bone. Am. J. Vet. Res., 52: 97-100.

Nunamaker, D.M., D.M. Butterweck and M.T. Provost, 1989. Some geometric properties of the third metacarpal bone: A comparison between the thoroughbred and standardbred racehorse. J. Biomech., 22: 129-134.

Nunamaker, D.M., D.M. Butterweck and M.T. Provost, 1990. Fatigue fractures in thoroughbred racehorses: Relationships with age, peak bone strain and training. J. Orthopaedic Res., 8: 604-611.

Ozyigit, G. and R. Ozcan, 2010. Cross-sectional geometry of equine metacarpal and metatarsal bones. J. Anim. Vet. Adv., 9: 971-975.

Parkin, T.D.H., N.P. French, C.M. Riggs, K.L. Morgan and P.D. Clegg *et al.*, 2004. Risk of fatal distal limb fractures among thoroughbreds involved in the five tpes of racing in the United Kingdom. Vet. Rec., 154: 493-497.

Parkin, T.D.H., P.D. Clegg, N.P. French, C.J. Proudman and C.M. Riggs *et al.*, 2006. Catastrophic fracture of the lateral condyle of the third metacarpus/ metatarsus in UK racehorses-fracture descriptions and pre-existing pathology. Vet. J., 171: 157-165.

Stover, S.M., R.R. Pool, R.B. Martin and J.P. Morgan, 1992. Histologic features of the dorsal cortex of the third metacarpal bone mid-diaphysis during postnatal growth in thoroughbred horses. J. Anat., 181: 455-469.

Turner, A.S., E.J. Mills and A.A. Gabel, 1975. *In vivo* measurement of bone strain in the horse. Am. J. Vet. Res., 36: 1573-1579.

Watkins, J.P., 2006. Etiology, diagnosis and treatment of long bone fractures in foals. Clin. Tech. Equine Pract., 5: 296-308.